Rec'd PCT/PTO 26 APR 2001
09/830496
WO 00/25393
PCT/IL99/00566

# GAS LASER

## FIELD OF THE INVENTION

The present invention relates to lasers generally and more particularly to gas lasers.

## BACKGROUND OF THE INVENTION

Various types of gas lasers are known in the art. RF excited diffusion cooled gas lasers having extended area thin gap electrodes are commercially available in both slab and annular configurations. Both the slab and the annular configurations require high frequency RF excitation in the typical range of 60 - 150 MHz in order to achieve uniform arc-free discharge. In lasers of this type, as contrasted from other types of gas lasers, power scales to electrode area and not to electrode length, thus enabling relatively compact lasers to be constructed.

Basic configurations of both slab and annular RF excited diffusion cooled gas lasers produced generally unusable beam shapes. The slab configuration produces a beam having an elongate thin line sectional structure, while the annular laser produces a beam having a thin annular sectional structure.

RF excited diffusion cooled gas lasers of both of the above configurations display undesirable voltage variation along the electrodes due to transmission line plasma phenomena. This voltage variation leads to unequal values of the E/N parameter along the length of the electrode and thus to reduced efficiency of the resonator. In slab electrodes, this difficulty is at least partially overcome by placing a plurality of inductors along the slab, thus reducing the voltage variations to a few

percent.

A general problem encountered in RF excited diffusion cooled gas lasers is alignment of optics with respect to each other and with respect to the thin gap electrodes. A general problem in RF excited diffusion cooled gas lasers having an annular configuration is undesirable creation of higher order modes in the lasing process which are difficult to filter out and which significantly degrade the quality of the output beam.

The following U.S. Patents are believed to represent the state of the art: U.S. Patent 4,847,852 which describes an RF excited diffusion cooled gas laser of the annular configuration; U.S. Patent 5,123,028 which describes an RF excited diffusion cooled gas laser of the slab configuration; and U.S. Patent 5,099,492 which describes a RF excited gas laser of the annular configuration.

SUMMARY OF THE INVENTION

The present invention seeks to provide an improved gas laser which overcomes limitations of the prior art.

There is thus provided in accordance with a preferred embodiment of the present invention a gas laser including:

an annular optical cavity defined by a pair of coaxial spaced electrodes which produces an annular coherent beam of a first diameter and a first thickness;

a mirror structure located at one end of the annular optical cavity and including:

a first mirror surface which is operative to decrease the diameter of the annular coherent beam from the first diameter and to expand the thickness of the annular coherent beam from the first thickness;

a second mirror surface which is operative to focus a beam reflected by the first mirror surface to a location located interiorly of the pair of coaxial spaced electrodes;

a third mirror surface located at an opposite end of the annular optical cavity; and

an output coupler operative to receive, reflect and transmit a beam reflected by the second mirror surface.

There is also provided in accordance with a preferred embodiment of the present invention a gas laser including:

an annular optical cavity defined by inner and outer coaxial spaced electrodes which produces an annular coherent beam; and

an RF power supply coupled to the outer electrode at at

least one location symmetrical with respect to the length thereof.

There is additionally provided in accordance with a preferred embodiment of the present invention a gas laser including an enclosure, an annular optical cavity defined by inner and outer coaxial spaced electrodes disposed within the enclosure and which produces an annular coherent beam and a plurality of RF power supplies mounted onto the enclosure and coupled to the outer electrode at multiple locations thereon distributed along the length and circumference thereof, thereby to provide generally homogeneous power and voltage distribution throughout the cavity.

There is additionally provided in accordance with an embodiment of the present invention, a gas laser including:

an annular optical cavity defined by inner and outer coaxial spaced electrodes which produces an annular coherent beam;

a grounded structure surrounding the annular optical cavity and including first and second portions having precisely formed first and second mating surfaces,

the first portion having machined thereon a first mirror structure located at one end of the annular optical cavity; and

the second portion having machined thereon a second mirror structure located at one end of the annular optical cavity.

In accordance with an embodiment of the present invention, the first mirror surface is an off-axis parabolic rotation-

ally symmetric surface.

In accordance with an embodiment of the present invention, the second mirror surface is an off-axis ellipsoidal rotationally symmetric surface.

Preferably, the annular optical cavity is defined by inner and outer coaxial spaced electrodes which produces an annular coherent beam and the gas laser also includes an RF power supply coupled to the outer electrode at at least one location symmetrical with respect to the length thereof.

Preferably, the inner electrode is grounded and there is provided a grounded structure surrounding the annular optical cavity.

In accordance with an embodiment of the present invention, first and second ends of the outer electrode are coupled to the grounded structure via a plurality of induction coils.

Preferably, the at least one location is a location centered with respect to the length of the outer electrode.

In accordance with an embodiment of the present invention, the mirror structure is grounded.

In accordance with an embodiment of the present invention, there is provided a grounded structure surrounding the annular optical cavity and including first and second portions having precisely formed first and second mating surfaces,

the first portion having machined thereon a first mirror structure located at one end of the annular optical cavity; and

the second portion having machined thereon a second

mirror structure located at one end of the annular optical cavity.

Preferably, the first mating surface and the first mirror structure are machined together so as to ensure desired alignment therebetween.

Preferably, the second mating surface and the second mirror structure are machined together so as to ensure desired alignment therebetween.

In accordance with an embodiment of the present invention, the first mirror structure includes:

a first mirror surface which is operative to decrease the diameter of the annular coherent beam from the first diameter and to expand the thickness of the annular coherent beam from the first thickness;

a second mirror surface which is operative to focus an annular beam reflected by the first mirror surface to a location located interior of the pair of coaxial spaced electrodes; and

a spatial filter disposed at the location located interior of the pair of coaxial spaced electrodes.

Preferably, the second mirror structure includes a third mirror surface located at an opposite end of the annular optical cavity.

In accordance with an embodiment of the present invention, the gas laser also includes an output coupler.

## BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description, taken in conjunction with the drawings in which:

Fig. 1 is a simplified sectional illustration of an RF excited diffusion cooled gas laser of an annular configuration constructed and operative in accordance with a preferred embodiment of the present invention;

Fig. 2 is a simplified sectional illustration showing the optical structure of the RF excited diffusion cooled gas laser of Fig. 1;

Fig. 3A is a sectional illustration taken along lines A - A in Fig. 2, showing the beam configuration along lines A - A;

Fig. 3B is a sectional illustration taken along lines B - B in Fig. 2, showing the beam configuration along lines B - B;

Fig. 3C is a sectional illustration taken along lines C - C in Fig. 2, showing the beam configuration along lines C - C;

Fig. 3D is a sectional illustration taken along lines D - D in Fig. 2, showing the beam configuration along lines D - D;

Fig. 3E is a sectional illustration taken along lines E - E in Fig. 2, showing the beam configuration along lines E - E;

Fig. 3F is a sectional illustration taken along lines F - F in Fig. 2, showing the beam configuration along lines F - F;

Fig. 3G is a sectional illustration taken along lines G - G in Fig. 2, showing the beam configuration along lines G - G;

Fig. 3H is a sectional illustration taken along lines H - H in Fig. 2, showing the beam configuration along lines H - H;

Fig. 3I is a sectional illustration taken along lines I - I in Fig. 2, showing the beam configuration along lines I - I;

Fig. 3J is a sectional illustration taken along lines J - J in Fig. 2, showing the beam configuration along lines J - J;

Fig. 3K is a sectional illustration taken along lines K - K in Fig. 2, showing the beam configuration along lines K - K;

Fig. 4 is a simplified sectional illustration showing the aspherical surfaces of the optical structure of the laser of Figs. 1 and 2;

Fig. 5 is a simplified illustration of the RF electrical structure of the laser of Fig. 1;

Fig. 6 is a simplified illustration of the opto-mechanical structure of the laser of Fig. 1; and

Fig. 7 is a simplified illustration of the RF electrical structure of an alternative embodiment of the laser of Fig. 1.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Reference is now made to Fig. 1, which is a simplified sectional illustration of an RF excited diffusion cooled gas laser 100 of an annular configuration constructed and operative in accordance with a preferred embodiment of the present invention. The laser of Fig. 1 comprises first and second enclosure elements 102 and 104, typically formed of aluminum, and an output coupler assembly 106.

Output coupler assembly 106 is mounted over an aperture 108 formed in an end of enclosure element 104. The output coupler assembly 106 preferably comprises an annular spacer element 110 and an mirror housing element 112 which secures an output coupler mirror 114 against spacer element 110. Output coupler mirror 114 may be any suitable output coupler mirror. When laser 100 is a CO2 laser, the output coupler mirror 114 is preferably a ZnSe mirror.

First and second enclosure elements 102 and 104 are joined together as shown in Fig. 1 to define an enclosure 116 in which are mounted respective coaxial inner and outer generally circular cylindrical electrodes 120 and 122, which are centered about a longitudinal axis 123. Inner electrode 120 is typically formed of aluminum and has a circular cylindrical configuration. It is mounted within enclosure 116 at one end by means of a cylindrical mounting element 124 which is fixed to an interior cylindrical surface 126 of electrode 120 and is tightly secured against corresponding interior surfaces 128 and 130 of enclosure element 104. Preferably an annular RF contact spring 134 is interposed between an end surface 136 of mounting element 124 and

a corresponding interior surface 138 of enclosure element 104.

Inner electrode 120 is preferably mounted at its opposite end to the interior of enclosure element 102 by means of a plurality of spider struts 140, typically three in number. Each spider strut 140 includes a first end 142 fixed to an end surface 144 of electrode 120, a central knife-like portion 146 and a second end 148 which is tightly seated in a cylindrical recess 150 formed in an interior surface of enclosure element 102. Preferably an annular RF contact spring 154 is interposed between an end surface 156 of the second end 148 of each spider strut and a corresponding interior facing surface 158 of recess 150.

Outer electrode 122 preferably comprises an integrally formed generally circular cylinder including a generally cylindrical inner recess 170 bounded by cylinder ends 172 and 174 having respective outwardly facing surfaces 176 and 178. Outer electrode 122 is preferably fixedly mounted onto respective interior surfaces 180 and 182 of enclosure elements 102 and 104 respectively by means of respective ceramic annuli 184 and 186 respectively. A generally cylindrical, electrically insulative, cover element 190 surrounds outer electrode 122.

Recess 170 defines a coolant circulation chamber, which preferably communicates with a coolant fluid supply (not shown) and a coolant fluid drain (not shown) via fluid communication conduits 194 and 195. The inner electrode 120 is also cooled preferably by cooling fluid passing through a channel 196 extending therethough via conduits 197 and 198.

A plurality of induction termination coils 199 are

formed in bores 200 located at locations distributed about the circumference of ceramic annuli 184 and 186.

An RF input connection 202 is provided at the center of the outer electrode 122 and comprises a metal rod 204 preferably surrounded by an insulator 206.

A cylindrical discharge gap 210 is defined between the inner and outer electrodes 120 and 122 in the region between ceramic annuli 184 and 186.

An inner facing surface of enclosure element 102 is preferably configured to define a first mirror surface 220, which is operative to decrease the diameter of an annular coherent beam formed in the discharge gap 210 from a first diameter and to expand the thickness of the annular coherent beam from a first thickness corresponding to the thickness of the discharge gap 210.

The inner facing surface of enclosure element 102 is also preferably configured to define a second mirror surface 222 which is centered about longitudinal axis 123. Second mirror surface 222 is operative to focus an annular beam reflected by the first mirror surface 220 to a location 224 located interior of the pair of coaxial spaced electrodes 120 and 122 and along longitudinal axis 123.

An inner facing surface of enclosure element 104 is preferably configured to define a third mirror surface 230, which, together with the first and second mirror surfaces 220 and 222 and the output coupler mirror 114 defines a laser resonator.

A spatial filter 240 is preferably located within inner electrode 120 at location 224.

Reference is now made to Fig. 2, which is a simplified sectional illustration showing the optical structure of the RF excited diffusion cooled gas laser of Fig. 1. It is seen that first mirror surface 220, which is preferably an off-axis paraboloidal rotationally symmetric surface, is operative to decrease the diameter of an annular coherent beam 250 from a first diameter corresponding to the diameter of discharge gap 210 (Fig. 1) and to expand the thickness of the annular coherent beam 220 from a first thickness T corresponding to the thickness of discharge gap 210 (Fig. 1). Thickness T is illustrated in Fig. 3A.

First mirror surface 220 is thus operative to provide a beam 252, a sectional illustration of which appears in Fig. 3B, which passes through a ring focus at a location 254. The cross section of beam 252 at location 254 is illustrated in Fig. 3C. Downstream of location 254, beam 252 expands sequentially as shown in the sectional illustrations of Figs. 3D and 3E.

Second mirror surface 222 is typically an off-axis, ellipsoidal rotationally symmetric surface and is operative to focus beam 252 reflected by first mirror surface 220 to location 224 located interiorly of coaxial spaced electrodes 120 and 122. Fig. 3F shows the beam as it is impinges on second mirror surface 222. The beam reflected by second mirror surface 222, designated by reference numeral 260, is a generally solid beam which is sequentially focussed, as illustrated in the sectional illustrations of Figs. 3G, 3H and 3I. Fig. 3I shows beam 260 at location 224.

Downstream of location 224, beam 260 sequentially

expands as illustrated in the sectional illustrations of Figs. 3J and 3K until it impinges on surface 270 of output coupler 114.

Third mirror surface 230, located at an opposite end of the annular optical cavity defined by discharge gap 210 is a flat mirror which reflects beam 250 back into discharge gap 210.

Output coupler 114 is operative to receive, reflect and transmit a beam 260 reflected by the second mirror surface 222. Output coupler 114 defines a first partially reflective surface 270 which is spherical and has a radius of curvature equal to the distance between the surface 270 and location 224 and is thus operative to reflect part of the beam 260 back to location 224. The remainder of beam 260, which is not reflected by surface 270 is collimated by a second surface 272 of output coupler 114 and exits as useful laser power.

Spatial filter 240, located at location 224 is operative to substantially prevent occurrence of high order modes, thus enabling the laser to operate in the lowest order mode.

It is a particular feature of the present invention described hereinabove that the mirror surfaces 220 and 222 are constructed such that location 254 lies at the common focus of both mirror surfaces 220 and 222. As seen in Fig. 4, mirror surface 220 is based on an off-axis section of a parabola 280. This off-axis section is rotated about axis 123 to define the annular mirror surface 220.

Similarly mirror surface 222 is based on an off-axis section of an ellipse 282. This off-axis section is rotated about axis 123 to define the mirror surface 222. Thus, it is appreciated that location 254 is located both at the focus of the parabola

280 and at one of the foci of the ellipse 282. Location 224 is located at the second focus of ellipse 282.

This structure ensures that substantially each light ray passing through location 254 arrives at location 224. In this way, an annular beam is effective transformed to a solid conical beam.

It is a particular feature of the invention that by varying the design of the laser to selectably position location 254, one may determine the diameter of the beam reflected from surface 222.

Mirrors 220 and 222 serve three important functions: They transform an annular beam into a solid beam of round cross section; they serve as intracavity expansion optics and they couple rear mirror 230 and output coupler 114.

Reference is now made to Fig. 5, which is a simplified illustration of the RF electrical structure of the laser of Fig. 1. As seen in Fig. 5, an annular optical cavity is defined by discharge gap 210 between by inner and outer coaxial spaced electrodes 120 and 122. An RF power supply 300 is coupled to the outer electrode 122 at at least one location 302 symmetrical with respect to the length of outer electrode 122. The RF power supply 300 is typically coupled to outer electrode 122 at location 302 via a conventional RF matching unit 304 and via RF input connection 202 (Fig. 1). The inner electrode 120 is grounded, preferably via enclosure elements 102 and 104.

Preferably RF power supply 300 is grounded and provides grounding of enclosure elements 102 and 104 via RF matching unit

304.

In accordance with a preferred embodiment of the present invention, first and second ends 310 and 320 of the outer electrode 122 are coupled to respective grounded enclosure elements 102 and 104 via a plurality of induction coils 199.

The provision of induction coils 199 is operative to reduce undesirable voltage variation along the electrodes due to transmission line plasma phenomena.

In accordance with a preferred embodiment of the present invention, the outer electrode 122 is insulated from ground by ceramic annuli 184 and 186 and by cover element 190, which is an insulator preferably formed of a polymer. This structure effective restricts discharge to the region bounded by ceramic annuli 184 and 186. Beyond this region, the thin gap cavity 210 extends, typically 15 - 25 mm, and thus the hot excited gas reaching the extension of cavity 210 is effectively cooled and quenched by diffusion to the walls of cavity 210. Thus only relatively cold and unexcited gas exits cavity 210, thereby preventing premature degradation of mirror surfaces 220 and 230, which are located a relatively short distance from the apertures of cavity 210.

It is a particular feature of the embodiment of Fig. 5 that the mirror surfaces 220 and 230 may be placed at a relatively short distance from the respective ends of cavity 210, typically less than 10 mm. This relatively short distance enables the wavefront exiting the cavity 210 to be maintained generally planar, providing optimal performance of the focusing optics 220, 222 and 270 and minimizing energy losses due to beam divergence.

Reference is now made to Fig. 6, which is a simplified illustration of the opto-mechanical structure of the laser of Fig. 1. It is seen that mirror surfaces 220 and 222 are preferably integrally formed with enclosure element 102, as by diamond turning. Similarly mirror surface 230 is preferably integrally formed with enclosure element 104, as by diamond turning.

Preferably, respective mating surfaces 350 and 352 of enclosure elements 102 and 104 at their junction, indicated here by reference numeral 354 are flat diamond turned surfaces. Preferably enclosure elements 102 and 104 are clamped together.

It is a particular feature of the invention that joined enclosure elements define an integral mechanical, optical and electrical structure for the laser. Inasmuch as surfaces 350, 220 and 222 may all be machined in a single operation, and similarly surfaces 352 and 230 may be machined in a separate single operation, mutual alignment of surfaces 220, 222 and 230 may be realized by mutual attachment of mating surfaces 350 and 352 at junction 354. This greatly simplifies the structure and assembly of the laser and significantly lowers its cost.

It is appreciated that the laser may be formed with multiple mating surfaces.

It is a particular feature of the present invention that the laser, with the exception of the output coupler, is formed entirely of aluminum. This enables thermal effects to be readily minimized.

Reference is now made to Fig. 7, which is a simplified illustration of the RF electrical structure of an alternative

embodiment of the laser of Fig. 1. As seen in Fig. 7, similarly to the embodiment of Figs. 1 - 6, an annular optical cavity is defined by discharge gap 210 between by inner and outer coaxial spaced electrodes 120 and 122.

As distinct from the embodiment of Figs. 1 - 6, in the embodiment of Fig. 7, an RF is coupled to the outer electrode 122 via multiple discrete solid state RF power supply units 402. Suitable solid state RF power supply units are commercially available from various suppliers including, for example, Delta Sigma Inc. of Riverside, California, U.S.A..

Solid state RF power supply units 402 are preferably mounted exteriorly of first and second enclosure elements 102 and 104 (Figs. 1 & 5) and provide power outputs at multiple locations at the outer electrode 122 (Figs. 1 & 5) as shown in Fig. 7, thereby to provide a generally homogeneous distribution of power and voltage along the length and circumference of the laser cavity.

A DC power supply 404 preferably supplies electrical power to the RF power supply units 402.

Preferably each RF power supply unit 402 is provided with a conventional RF matching unit 406 which outputs via an RF input connection 408.

As in the embodiment of Figs. 1 - 6, the inner electrode 120 is grounded, preferably via enclosure elements 102 and 104.

Preferably DC power supply 404 is grounded and provides grounding of enclosure elements 102 and 104 via RF power supply units 402.

In both the embodiments of Figs. 1 - 6 and Fig. 7, the provision of a plurality of induction coils 199 is optional.

As in the embodiment of Figs. 1 - 6, the outer electrode 122 is insulated from ground by ceramic annuli 184 and 186 and by cover element 190, which is an insulator preferably formed of a polymer. This structure effective restricts discharge to the region bounded by ceramic annuli 184 and 186. Beyond this region, the thin gap cavity 210 extends, typically 15 - 25 mm, and thus the hot excited gas reaching the extension of cavity 210 is effectively cooled and quenched by diffusion to the walls of cavity 210. Thus only relatively cold and unexcited gas exits cavity 210, thereby preventing premature degradation of mirror surfaces 220 and 230, which are located a relatively short distance from the apertures of cavity 210.

It is noted that the embodiments of Figs. 1 - 6 and of Fig. 7 provide alternative solutions to the problem of voltage variations leading to unequal values of the E/N parameter along the length of the electrode and thus to reduced efficiency of the resonator. The solution of Fig. 7 is applicable to slab lasers as well as to co-axial lasers.

It will be appreciated by persons skilled in the art that the present invention is not limited to what has been particularly shown and described hereinabove. Rather, the present invention includes also combinations and subcombinations of the various features described hereinabove as well as modifications and additions thereto as would occur to a person skilled in the art upon reading the foregoing description and which are not in

the prior art.